Field Measurement Of Existing Noise Levels

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NEW YORK STATE DEPARTMENT OF TRANSPORTATION
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CONTENTS

INTRODUCTION

In the late 1960's, concern in many circles turned increasingly to our environment. Various laws were passed, designed to achieve minimum quality standards for air, water, and land, and to abate the waste of our natural resources. A fourth pollutant, less frequently recognized, is noise. The collection of sounds created by our advanced industrial society has reached a level that can no longer be ignored. One has merely to stand on a crowded city street corner during rush hour to realize the importance of controlling noise.

A major contributor to the noise in our daily lives is the ever-increasing stream of automobiles and trucks riding our nation's highways. Thus, in 1970, legislation was passed that resulted in noise standards designed to control the increasing noise levels associated with highway traffic. These standards were set forth by the Federal Highway Administration (FHWA) in its Policy and Procedure Memorandum 90-2 (Appendix G).

To implement these standards, and in doing so, to help maintain and improve the quality of our environment, the New York State Department of Transportation has created a program to measure highway-related noise. One outgrowth of this program is the Noise Measurement Unit of the Materials Bureau in Albany, which has overall responsibility for noise measurement for the entire Department. Also, each region has designated a Regional Noise Liaison Engineer (RNLE) whose responsibility is to supervise the regional noise measurement program.

The ten regional noise measurement units are charged with measurement and analysis of noise as it relates to the Department's construction program. The Main Office Noise Measurement Unit's function is to support the regional units with training, equipment allocation, computer record maintenance, and general coordination of a quality noise measurement system. A third group, the Environmental Analysis Section, is part of the Development Division. One of its functions is to provide support for the regional noise analysis effort.

As a Noise Measurement Technician (NMT), you are the field arm of this organization. It is you, the NMT, who will be measuring noise in the field. This manual is written specifically for you. It's designed to be both a field guide and a reference explaining the basic science of sound, noise, and noise measurement. It has three sections:

I. Sound and Noise Fundamentals.

II. Measurement of Existing Noise.

III. Noise Field Test Methods.

Section I gives the basic science of sound and noise -- what they are and how they are defined for measurement purposes.

Section II deals with the specifics of noise measurement, with emphasis on highway-related noise.

Section III gives field test methods for noise measurement, explaining in detail the equipment and procedures and the necessary paperwork.

One further point -- as a Certified NMT, you have a particularly high level of responsibility. Noise must be measured by strictly adhering to field test procedures. Mistakes in obtaining noise data are not always readily detectable. If the data appear incorrect, the only alternative is to go out and re-measure for verification. Unfortunately, many times this is not possible.

Your measurements will be one factor in transportation decisions. Once you are a Certified NMT, the Department will have to rely on your measurements, and possibly even defend them in court.

Everyone in the state will benefit if we reduce noise levels. Noise is here to stay, but with your help, we can design measures to control it. Doing your job to the best of your ability will help improve our environment.

I. SOUND AND NOISE FUNDAMENTALS

A. Sound Waves

Since we are concerned with noise it seems logical to start with the question: what is noise? The best definition is the most simple. Noise is unwanted sound. Fine. But what is sound? We've taken it for granted since childhood. We hear "sounds." Technically, sound is defined as a wave disturbance moving through an elastic medium at a speed characteristic of that medium. That really doesn't help much. Let's try it this way. On a nice day you're sitting by a lake. The surface of the water is relatively flat. You're fishing for bass. They aren't biting, so you pick up a rock and toss it into the lake. When the rock hits the water it causes waves in the form of rings that move outward for the point where the rock enters the water. The rock has disturbed the water from its equilibrium (flat) level, and the waves move outward and eventually die out.

Now, as we said, sound is also a wave. The difference between the water wave and a sound wave is that sound is a disturbance in the air. More correctly, the sensation of "sound" is caused by the ear detecting changes from atmospheric pressure. When a bass drum is struck, the drumhead begins vibrating (rapidly moving up and down), causing waves in the air, just as the rock caused waves in the water. These waves are detected by our ears as very tiny changes from the equilibrium (or atmospheric) pressure. These pressure changes are converted through the internal workings of the ears into a message that is sent to the brain. The result is that we "hear" the sound of the bass drum.

Water waves, sound waves, and in fact, all waves can be described by two characteristics:

1. AMPLITUDE.

2. FREQUENCY.

In the case of the water waves caused by the rock, the amplitude of the wave is the height of the water above or below the undisturbed (flat) water surface. Another way of saying this would be that the amplitude of the wave is equal to the "magnitude" (height) of the "disturbance" (change in water level) above or below the "reference" or "equilibrium" level (undisturbed flat water surface).

Now suppose a pole were sticking out of the water near where the rock hits. If we counted the number of waves passing the pole for, say, 5 seconds and divided that number by the 5-second time, we would know the frequency of the wave. In other words, the frequency of the wave is equal to the number of

waves occurring in a unit of time. One complete wave is known as one cycle. In the case of the bass drum, when the drumhead is struck it is pushed down. The drumhead then springs back up, completing one cycle. The number of times it springs up and down (vibrates) per unit of time is the frequency of the sound wave produced.

For the case of a water wave, Figure 1 shows the relationship between frequency and amplitude. Case 1 shows an amplitude of 1 in. above and below the equilibrium water level and a frequency of 1 cycle (i.e., one complete wave) in 10 sec, or 0.10 cycles per second. The term "cycles per second" has been given the special name hertz, abbreviated Hz. Therefore, 1 cycle per second equals 1 Hz. In Case 2, the wave has an amplitude of ± 1 in. and a frequency half that of Case 1, or 0.05 Hz. In Case 3, the frequency is the same as in Case 2, but the amplitude is now 2 in., or twice that in the other two cases.

To summarize briefly, noise is unwanted sound. Sound is a wave disturbance in the air similar to a water wave. They are similar because all waves can be described by two characteristics -- amplitude and frequency. For a sound wave, the amplitude is the magnitude of the variation from atmospheric pressure, and the frequency is the number of disturbances per second. Frequency is expressed in hertz, abbreviated Hz.

One further comment -- the sound we will measure in the field is composed of not only one sound wave, but is a summation of a number of separate sound waves, each with a different frequency and amplitude. These different waves add up to produce the overall sound wave. An example of this is an orchestra. Each instrument produces a sound wave, and they all add up to give the orchestra's overall sound.

B. Sound Pressure Level

The human ear is sensitive to a large range of pressure disturbances. The change from atmospheric pressure caused by a cricket chirping at night is very tiny compared to the change from atmospheric pressure caused by a jet engine at an airport, yet the human ear can detect either.

Because of this large range of pressure disturbances that the ear can detect, it would not be practical to compare sound waves on the basis of pressure disturbances. To use the water wave example, this would be like comparing the ripples in a puddle to a tidal wave. So, to compare sound wave amplitudes, we use sound pressure level (abbreviated SPL), which is defined in such a way that the large pressure ranges possible are compressed into a smaller scale. (How this is done is explained in Appendix F.) The units of sound pressure level are called decibels.

The sound pressure level in decibels (abbreviated dB) then allows us to compare sound wave amplitude without the problems that we would have if we tried to compare them directly in terms of pressure disturbances. Figure 2 gives SPLs, in decibels, for various common indoor and outdoor sounds. The SPL of a person talking at a distance of 3 ft is about 65 dB. A jet airplane at 1,000 ft causes a much larger disturbance; hence, the SPL is 105 dB.

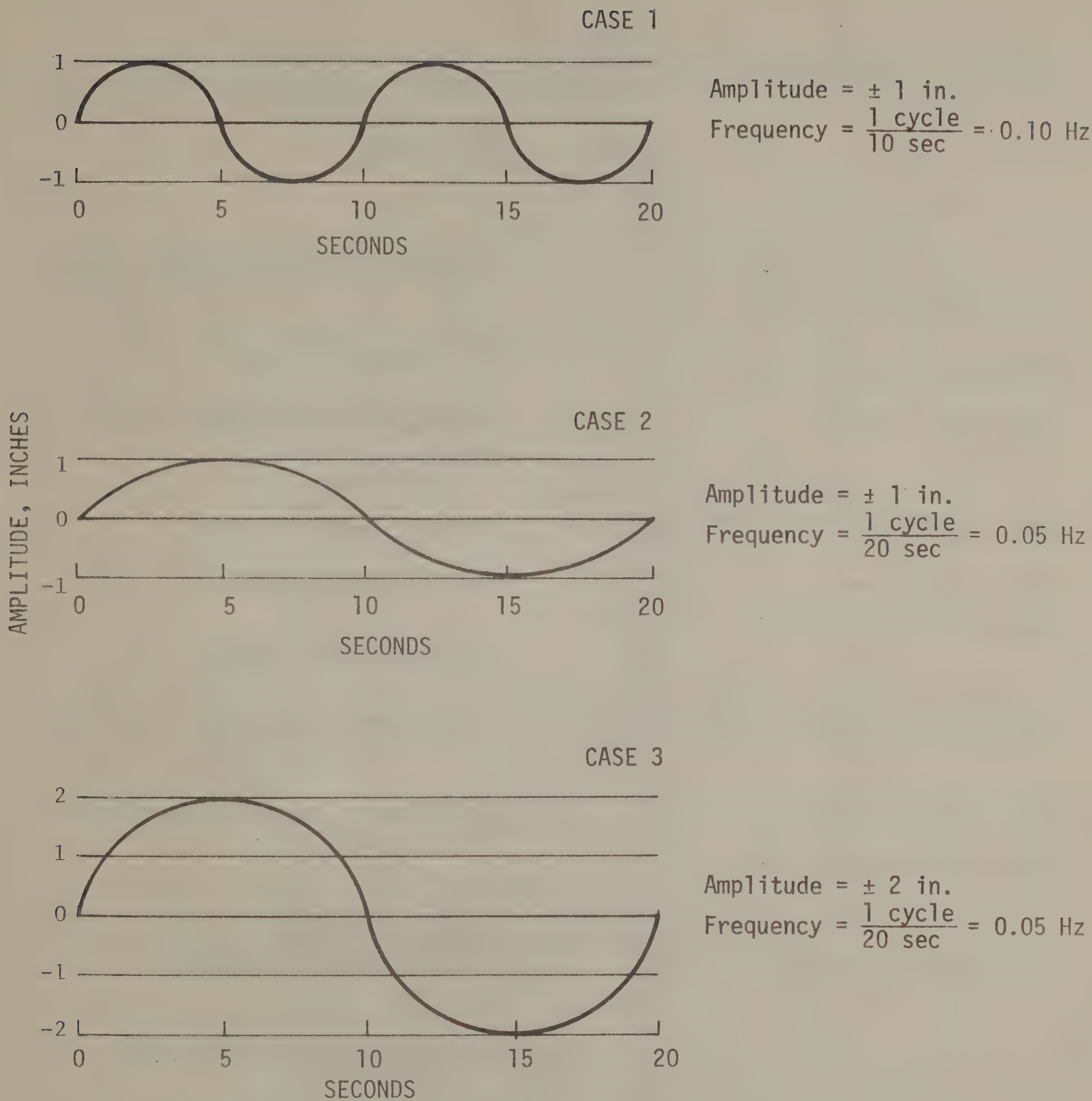


Figure 1. Frequency and amplitude of water waves.

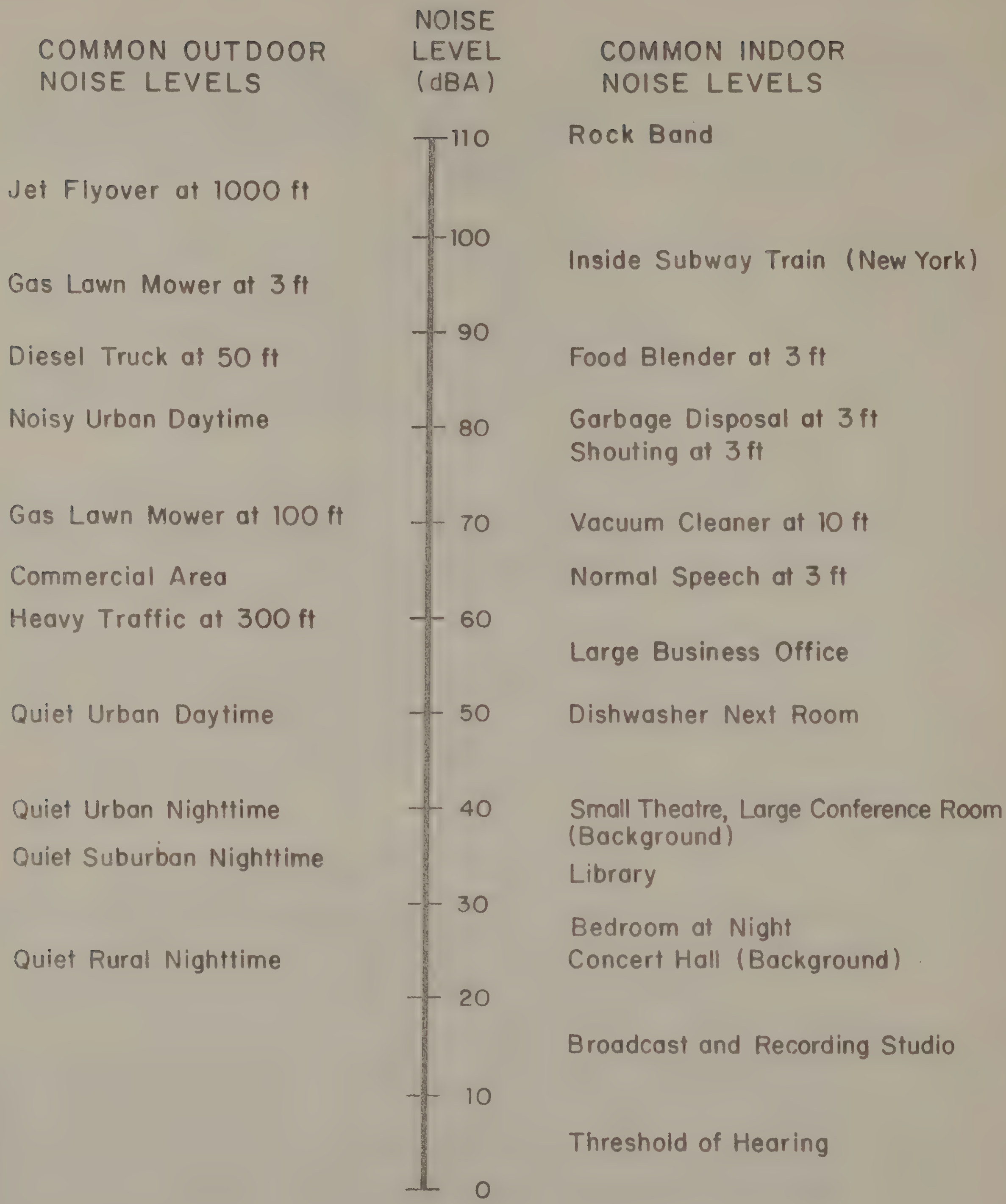


Figure 2. Common indoor and outdoor noise levels.

To summarize again, noise is unwanted sound. Sound is a pressure disturbance and Sound Pressure Level or SPL is related to the magnitude of this disturbance. The units of SPL are decibels, abbreviated dB.

C. Addition of Decibels

There is one important difference between decibels and, for example, feet or pounds. If two boards are each 10 ft long, then their total length is 20 ft. However, if two trucks each create a SPL of 70 dB, then their total SPL is not 140 dB but only 73 dB. (This is because of the mathematical definition of SPL in dB; this definition and a proof of the above are given in Appendix F.)

Using the following table and method, any number of sound pressure levels may be added with an accuracy of ± 1 dB.

When two decibel values differ by	Add the following amount to the higher value
0 or 1 dB	3 dB
2 or 3 dB	2 dB
4 to 9 dB	1 dB
10 or more dB	0 dB

To illustrate, we will add the following levels: 69, 89, 84, 74, and 78 dB. The first thing to do is rank the sound pressure levels in ascending order. They are then added pair-wise, according to the preceding table, beginning with the lowest pair:

69 =75 =80 =85 =90 dB
74
78
84
89

69 dB + 74 dB = 75 dB
75 dB + 78 dB = 80 dB
80 dB + 84 dB = 85 dB
85 dB + 89 dB = 90 dB

Notice also that for differences of 10 dB or more, the number of decibels added to the higher value is zero. This means that if one sound is stronger than another by 10 dB or more, the lower sound is effectively "drowned out" by the higher one. This effect is called "masking."

D. The A-Scale Weighting Network

Just as the human ear is sensitive to a large range of pressures, it is also sensitive to a large range of frequencies. For most people, the normal fre-

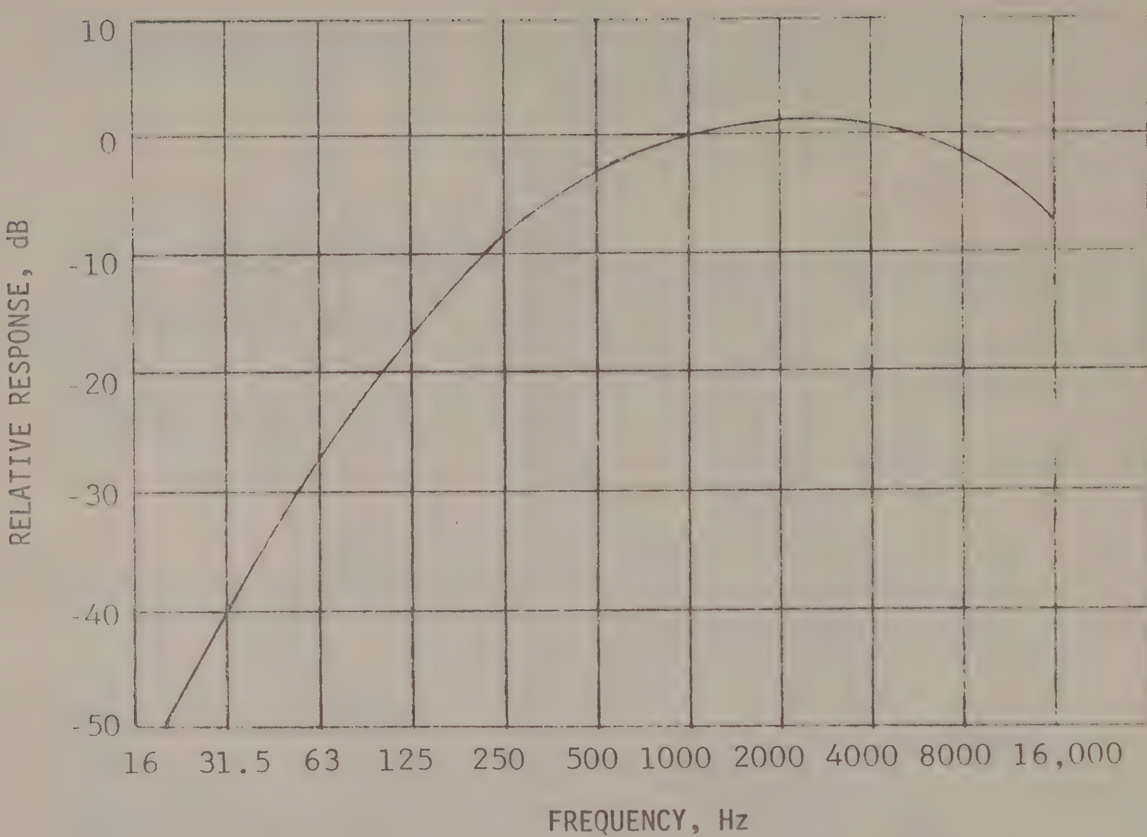


Figure 3. Electrical frequency response specified for the A-scale filter of sound level meters (ANSI SI.4-1971).

quency range of hearing is from 20 to 10,000 Hz, and in some cases as high as 20,000 Hz. However, the human ear does not "hear" each frequency equally. It is less sensitive to low-frequency sound than to high-frequency. Since we want to measure noise in a way that compares closely to the human ear's sensitivity, the A-scale weighting network has been devised.

The A-scale network (within the measuring equipment) electronically adjusts some of the higher and lower frequencies when the SPL is measured. The sound-measuring device then responds in a manner very close to the response of the average human ear, givin us a good idea of how the average person would perceive that sound.

The A-scale changes the SPL as shown in Figure 3. From this graph it can be seen that at 100 Hz, the SPL is diminished by 20 dB. At 1,000 Hz the SPL is not changed at all, while at 2,000 Hz, the SPL is increased by 1 dB.

From this point on, we will no longer use the term SPL in dB, but rather the term "sound level." By this we will mean an SPL measured in dB with an A-weighting network. Thus, sound level will mean the result of an A-weighted measurement. Any sound level will then be an approximation to the response of a human ear. Also, for our sound levels from here on, the results will be

reported as dBA, not dB. Thus, if the sound level of a passing car were measured, the results would be reported as 67 dBA, not 67 dB.

E. Sound Reduction and Reflection

When the rock in the water-wave example hit the water, waves were created and radiated outward at a certain speed. As they moved farther and farther out, they became smaller (attenuated) until they finally disappeared.

The same thing happens with a sound wave -- the farther from the sound source, the smaller the disturbance. Consequently, the sound level decreases with distance from the source. For example, the farther you are from a truck moving down the highway, the lower the sound level will be. If there is a high concrete wall between you and the highway, the sound level will be still lower, because some of the sound the truck generates will be reflected away by the wall. This can also work in reverse. If a building is close behind you, some of the sound waves may be reflected back to you, causing the sound level of the truck to be higher than it would be without the reflected sound. Rows of houses or possibly even a densely wooded area between you and the highway may also reduce the sound level.

The reason for mentioning these facts will become apparent later in this manual when we discuss the selection of measurement sites. For now, however, it is important to remember the following rules which apply to a site having an unobstructed view of the highway:

1. For a single car or truck proceeding down a highway, for every doubling of the distance from the road the sound level should drop approximately 6 dBA.

2. For a line of cars -- that is, a fairly uniform stream of traffic -- for every doubling of the distance from the road the sound level should drop approximately 3 dBA.

"Doubling the distance" means that if you are 50 ft away and get a sound level of 59 dBA, then at 100 ft you should get 53 dBA for a single car and 56 dBA for a stream of traffic.

This concludes our discussion of the fundamentals of sound and noise. It has been very basic. Appendix E of this manual gives references for further reading.

II. MEASUREMENT OF EXISTING NOISE

A. Traffic-Related Noise Sources and Existing Noise

1. Existing Noise

In Section I, we explained how the sound we measure is not simply one wave, but a combination of waves like an orchestra. In the field, a combination of sounds exists produced by activities usually occurring around a site. This combination of sounds is commonly referred to as existing or ambient noise.

The existing noise level is obtained by measuring the sound level produced by those activities normally occurring in the site area. In the case of a site located close to a highway, a major portion of the existing noise will be from vehicles traveling down the road. If we are near a highway close to an airport, existing noise will also include noise of the aircraft. We will say more about existing noise in a later section. For now, it is sufficient to remember what existing noise is.

2. Automobiles, Trucks, and Other Vehicles

In most cases, we will be measuring existing noise whose major component is from highway traffic. Extensive measurements have shown that you can expect automobile sound levels to vary between 60 and 75 dBA and truck sound levels from 75 to 90 dBA or more at about 50 ft from the roadway. The large variations are due to such things as vehicle acceleration, speed, and condition; tire tread condition and type; and roadway surface roughness and grade.

Since there are relatively large variations between automobiles and trucks, we can see that it is very important to know how many trucks go by and how many automobiles; if we had only trucks going by, the existing noise level would generally be higher than if we had only cars.

Knowledge of the number of cars and trucks is necessary to help predict future sound levels, since it is reasonable to assume that altering an existing highway or putting a new highway in an area may increase traffic or change the relative number of automobiles and trucks, possibly resulting in higher noise levels. This may necessitate control measures.

Now, although this may sound silly, for our measurements what is a car and what is a truck? And how about motorcycles? Everyone has heard a souped-up sports car. Some are very loud. Some motorcycles are also quite loud --

as loud or louder than some trucks. To solve this problem, we will observe the following rules in determining the classification of a vehicle:

1. There will be three general classes -- automobiles, trucks, and motorcycles. Separate counts of automobiles and trucks will be kept.

2. An automobile will be any four-tire, two-axle vehicle including sports cars, pickup trucks, and small vans.

3. A truck will be any six-tire, two-axle, or larger vehicle including school buses, commericial buses, and walk-in vans.

4. A motorcycle will be treated as either a car or truck depending on how loud it is. Although this may seem a very doubtful way to classify them, a little field experience will show that it is quite easy to determine if a motorcycle is considered as loud as an automobile, it will be counted as an automobile and one vehicle will be added to the automobile count. Similarly, a motorcycle as loud as a truck will be counted as a truck.

Now, let's look at how we should go about taking measurements.

B. Basic Principles of Existing Noise Measurement

Measurement of noise for evaluation and possible control requires 1) a device that measures sound level, 2) a plan of where and when to measure, 3) a measurement method for collecting the noise data, and 4) a method to record and reduce the data. Stated more simply:

1. Equipment -- what do we use to measure?

2. Site and time selection -- where and when do we measure?

3. Method -- how do we measure?

4. Data Recording and Reduction -- what do we do with the measurements?

1. Measurement Equipment: The Sound Level Meter

Noise can be measured in many ways, using many types, sizes, and kinds of equipment. The most basic piece of equipment for measuring sound level is the sound level meter. All sound level meters perform the same basic function -- they measure the sound level. Components and controls are similar on most models. Components usually consist of a microphone, an amplifier, an A-weighting network, and a meter calibrated in decibels. The controls include an on-off switch, a meter response setting (fast-slow), a battery check switch, a weighting network selector, and a range switch. In addition, there is usually a calibration adjustment. (The functions of each of these controls for our equipment will be explained in Section III.)

Just as with any piece of equipment, the sound level meter has certain operating limitations. For instance, the microphone attached to the meter is sensitive to humidity and also to dirt, which can ruin it. If it becomes too moist it will not function properly. Temperature can have an effect on the electronics of the meter. High winds may also affect the measurements.

2. Selection of Measurement Sites and Times

Once the equipment to perform the measurements is chosen, the next step is to decide where and when to measure. Deciding "where" is actually a two-stage process. The general location of a measurement site is normally indicated on a map of a proposed project. This general location is selected by careful study of the map, and/or by preliminary field investigation.

The exact site location in the field is selected by the measurement team. The most important fact to remember in selecting a site is that measurements need to be representative of that area. So, in general, the site should not be chosen close to a building, or a tree, or any object that might distort the sound field.

However, it should also be understood that sometimes measurements may be needed from an area full of reflective surfaces (e.g. trees in a wooded area). These sites should be measured as specified by the RNLE, noting any special circumstances that are present.

It is also important to know the location of the site. This should be done by drawing a small diagram showing approximate footage from a distinguishing landmark or from the roadway if the site is near one. The distance from the landmark or roadway should be paced off, or tape-measured if so desired by the RNLE.

The "when" to measure is very dependent on what type of measurements are being taken. We may want to measure a particular site at a particular time. Since this is not always possible, the data should also include the time of the measurements. For instance, we may want to measure the effect of a highway on a site located close to a school. At the time the measurement team is present, school may just be letting out. It may be necessary to come back when classes are in session. In any event, the fact that school was just getting out should be noted along with the time the measurements were taken.

3. Measurement Method

Let's assume the site and time have been selected and the sound level meter is operating properly. Now what? The needle on the meter swings up and down as vehicles pass by. Do we read it when the car or truck is 10 ft down the road or when it is right in front of us? What do we do when no vehicles pass by? The noise at a site varies continuously with time -- that is, at any particular time, there is a certain sound level. This sound level changes continuously. Since sound varies with time, it would be best to take measurements as a function of time. By this we mean that

we select a time interval -- say, 10 seconds -- and every 10 seconds we read the meter. The sound level is recorded each time and after a sufficient period we will have accumulated a number of readings. We can then reduce these in some way to obtain the existing noise level at the site.

4. Data Recording and Reduction

At each 10-second interval, when the meter is read, a value for the sound level is obtained. How do we handle these data and reduce them to a meaningful form? We could write down each reading. An easier method would be to check off the readings as we measure them, on a form having preprinted values on it. Then all that would be necessary would be to put a check near the appropriate value each time it occurs.

This brings us to the question of how many readings we take; also, what do we do with them? FHWA currently states its design noise levels in PPM 90-2 on the basis of a quantity called L_{10}. This is the existing noise level exceeded 10 percent of the time. L_{50} and L_{90} are also used in some computations, and are the sound levels exceeded 50 and 90 percent of the time. How do we find these quantities? Suppose we have obtained the following set of 100 readings:

dBA			Total Readings
	L_{10}		
68	X X X		3
67	X X X X X X X X		8
66	X X X X X X X X X X X		11
65	X X X X X X X X X X X X X X X		15
64	X X X X X X X X X X X X X X X X		16
63	X X X X X X X X X X X X X X X X	L_{50}	16
62	X X X X X X X X X X X X X X		14
61	X X X X X X X X X X		10
60	X X X X X X X	L_{90}	7
			100

L_{10} is the level exceeded 10 percent of the time and there are 100 readings; 10 percent of 100 is 10. Therefore, L_{10} is the decibel level in which the tenth reading occurs. So, starting from the top, we count down the readings until we reach the tenth reading. In this case, L_{10} would be in the second group of readings -- that is, 67 dBA, since the tenth reading occurs in that group. Similarly, for L_{50} and L_{90} we count down from the top to the fiftieth and ninetieth readings. L_{50} would be 64 dBA and L_{90} would be 61 dBA.

Now by applying statistical analysis, we can find L_{10} within certain limits -- that is, ± 3 dBA -- and be 95 percent sure that L_{10} is really within that range. (The mathematics behind the computation of L_{10} ± 3 dBA are given in

Appendix D.) To do this, we use a special table which we will explain in Section III.

We have now looked at the what, where, when, and how of measuring existing noise, and this concludes our general discussion. What remains are the specific field test methods we will use when measuring existing noise.

III. NOISE FIELD TEST METHODS

A. Method 1: Measuring Existing Noise Level by the Check-off Method

1. Scope

This test method prescribes procedures for measurement of existing noise levels, using the Bruel and Kjaer (B&K) Type 2206 precision sound level meter. Instructions for documentation are included. (For those regions using the B&K Type 2205 meter, all procedures apply but attention should be paid to equipment limitations, possible differences in calibration, etc.)

2. Equipment

a. Equipment Required

1. B&K Type 2206 precision sound level meter with Type 4148 condenser microphone.
2. B&K Type 4230 calibrator.
3. Windscreen.
4. Wind velocity meter.
5. Extension cable.
6. Tripod.
7. Clipboard and counter.
8. Sling psychrometer.
9. Stopwatch.
10. Spare batteries.

b. Equipment Descriptions

1. Sound Level Meter with Condenser Microphone

This meter is a battery-operated precision instrument used to determine SPL in dB (Fig. 4). Its features and controls are as follows:

a. Power Switch

This is a four-position switch marked "off," "fast," "slow," and "batt." "Off" is self-explanatory, "fast" and "slow" refer to how quickly the meter responds to an incident sound wave, and the "batt" position allows the battery to be checked.

b. Range Switch

This is turned to change the reading range of the meter. The range indicator window on the meter shows the range value selected. The meter scale (Fig. 5) has a range of 20 dB. When the needle points to the right of the line beneath the range indicator window, the sound level is the meter scale reading plus the figure in the window. Readings to the left of the line under the window are subtracted from the figure in the window. It is best to attempt to keep the needle in the positive portion (e.g. the 75-dB reading in Fig. 5) since this is easier to read and more accurate.

c. + 10 dB Button

This increases the range of the meter face by automatically adding 10 dB to whatever value is in the range indicator window.

d. Sensitivity Adjustment

This small screw will change the needle position on the meter, and is used in calibrating the meter.

e. Weighting Network Selector

This should be set on "A" at all times.

f. Microphone

This precision condenser microphone (Fig. 6) can be unscrewed and removed from the meter. Take care not to damage the contacts when removing it. Also, do not remove the grid on top of the microphone at any time. If the meter and microphone are taken to

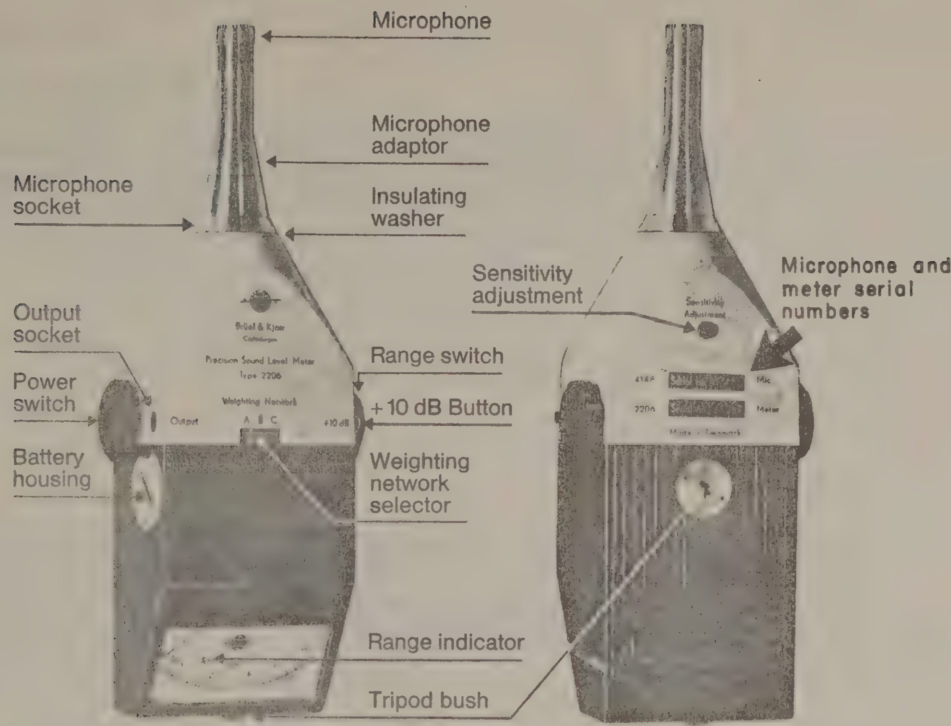
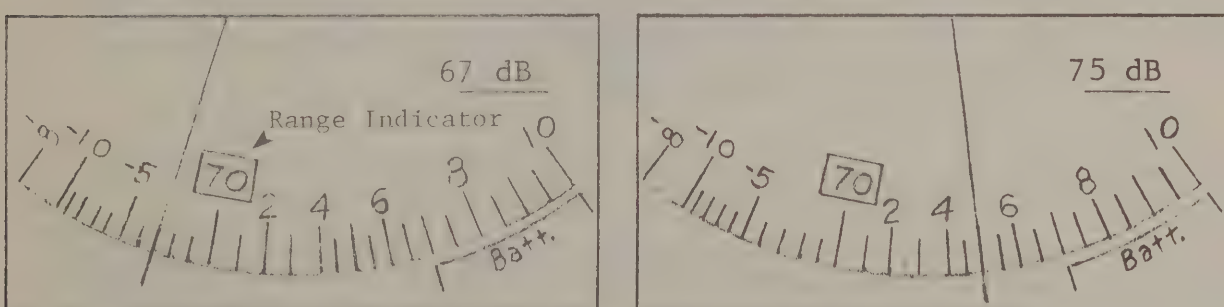


Figure 4. Front and back views of the sound level meter and microphone.



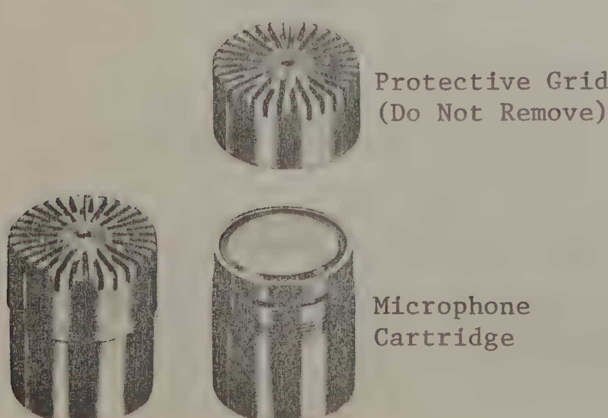


Figure 5 (above). Meter scale at two decibel levels.

Figure 6 (left). Condenser microphone.

a site inside a warm vehicle on a cold day, condensation may form when the microphone is set up outside. Under such conditions, transport the microphone and meter in your car's trunk.

2. Calibrator

This is used to calibrate the sound level meter. The calibration signal for the Type 2206 meter is 93.8 dB.

3. Windscreen

This round foam ball is placed over the microphone to eliminate noise caused by wind blowing across it. It is effective up to 12 mph, at which speed measurements are to be discontinued. Always use the windscreen, even on still days, since it also protects the microphone from dust.

4. Wind Velocity Meter

Instructions for use are printed on the back of this meter: "To use, face the wind. Hold meter in front of you in vertical position and with scale side toward you. Do not block bottom holes. Height of ball indicates wind velocity. For high scale, cover hole at extreme top with finger." Take wind velocity readings at the beginning of each measuremnt period.

5. Extension Cable

Always use an extension cable. It keeps the bulk of the meter and operator from causing a reflection of sound waves, thus affecting the reading. It also allows the operator to sit away from the tripod during readings. The cable connects the meter to the microphone. Do not touch any of the contacts, and keep them as clean as possible.

6. Tripod

Support the microphone on the tripod 4 to 5 ft above the ground.

7. Clipboard and Counter

A legal-size clipboard is supplied with a counter attached. The counter can be used to keep track of the number of readings or to aid in vehicle counts.

8. Sling Psychrometer

Noise cannot be measured when the relative humidity rises above 90 percent. Higher humidity causes condensation on the microphone, rendering it useless until it dries. The psychrometer thus is used to determine relative humidity. The manufacturer's operating instructions are reproduced on the next page. Measure relative humidity twice daily, usually in the morning and afternoon.

9. Stopwatch

Use for readings every 10 seconds.

c. Calibration of the Sound Level Meter

The calibrator has a calibration signal of 93.8 dB at 1,000 Hz. When the calibrator is placed on the microphone, the meter should read 93.8 dB. If it does not, adjust the calibration as follows:

1. Set the range indicator on 90 dB, warm up for 1 to 2 minutes, and check that the microphone and adapter are firmly screwed on.

2. Turn the power switch to "batt" and check the battery. The needle should swing to the red portion of the meter window. If it does not, replace the meter battery.

3. Turn the power switch to "slow."

4. Place the calibrator on the microphone. Be careful not to damage the plastic adaptor on the calibrator.

5. Press the button on the calibrator.

6. Adjust the meter to read between 93.5 and 94.0 dB by turning the sensitivity adjustment screw on the back of the meter with the small screwdriver provided in the meter box. Do not touch the zeroing screw on the meter front.

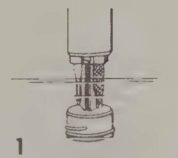
7. The calibrator will automatically turn off after about 1 minute. If the signal lasts only a few seconds, replace the calibrator battery as follows:

    a. Remove the black leather case.

    b. Unscrew the bottom black part of the calibrator housing.

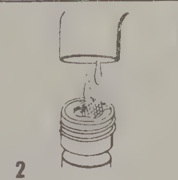
    c. Unsnap the contacts to the battery. Pry the metal clips off. Do not pull on the plastic; this will break the wires.

Remove cap; immerse end of body, to saturate wick.



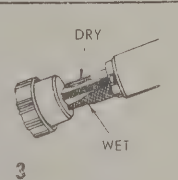
1

Fill psychrometer reservoir with water. Replace cap.



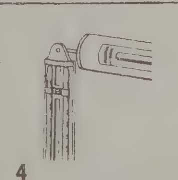
2

Be sure — wick covers "wet" bulb . . other bulb is dry.



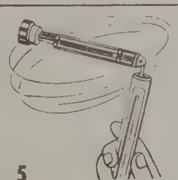
3

Pull body from tube until body hangs free.



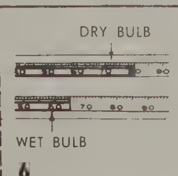
4

Use tube as handle; whirl body about 1 ½ minutes.



5

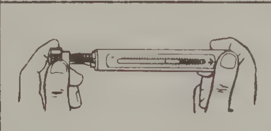
Read wet and dry bulb thermometers; replace body in tube.



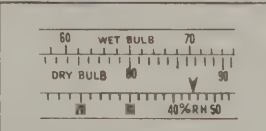
6

INSTRUCTION DRAWING
Do not use for ordering parts

See Parts List on Last Page



7 Set thermometer readings on upper two calculator scales.



8 Read relative humidity % indicated by arrow.

OPERATION

Before using, WICK (A) should be thoroughly saturated with water. Remove END CAP (B) and immerse PSYCHROMETER BODY (C) up to mercury reservoir on the thermometers until WICK is thoroughly wetted. Fill END CAP with water and replace; tighten just enough to prevent leakage.

To use:

1. Be sure WICK (A) is wet and covers mercury reservoir on WET BULB THERMOMETER (D). Be sure mercury reservoir on other THERMOMETER (F) is dry.
2. Pull TUBE (E) clear of BODY so BODY can swivel.
3. Holding TUBE, whirl body two to three revolutions per second (120 to 180 RPM).
4. Continue whirling until temperatures stabilize (1 ½ minutes is usually ample).
5. Immediately read WET BULB THERMOMETER (D) and then DRY BULB THERMOMETER (F). (See application instructions.)
6. Set wet and dry bulb temperatures opposite each other on slide rule type calculator scales, sliding BODY into TUBE as required.
7. Read % R.H. (per cent relative humidity) indicated by arrowhead on lower scale.

APPLICATION

Wet bulb temperatures should be read first and as quickly as possible for highest accuracy. Delay in reading may cause error. In addition, the wick must be kept clean, saturated with water, and whirled long enough to stabilize temperatures.

Range of the psychrometer is from 10% to 100% R.H. for dry bulb temperatures of 30° to 100°F. or –5° +50°C.

In addition to the above instructions, barometric pressure and other factors will influence exact relative humidity determinations to a very minor degree. For precise work, use psychrometric chart or set of tables such as W.B. No. 235 "Psychrometric Tables for Obtaining the Vapor Pressure, Relative Humidity, and Temperature of the Dew Point" which can be purchased from Superintendent of Documents, United States Government Printing Office, Washington, D. C. However, accuracy of the Psychrometer is satisfactory for all except most exacting work.

MAINTENANCE

WICK (A) should be kept clean; when dirty, cut off below WET BULB THERMOMETER (D) and pull clean section out of END CAP (B) and slide over bulb on WET BULB THERMOMETER.

WICK REPLACEMENT KIT may be purchased separately (refer to parts list). One or two extra WICKS may be kept in END CAP and will help retain moisture longer. Pack WICKS loosely to allow thorough water saturation and ample water supply to WET BULB THERMOMETER.

THERMOMETERS (D) and (F) are replaceable by backing off SCREWS (G) and loosening THERMOMETER CLIPS (H). To separate BODY (C) and TUBE (E), drive ROLL PIN (I) out of eye in PLUG AND SWIVEL ASSEMBLY which then may be slid out back end of TUBE.

d. Replace the battery with a new 9-volt battery.

e. Re-snap the contacts, replace the housing, and return the unit to its case.

The calibrator's leather case is for protection and should be left on except when changing batteries. It protects against dust and the effects of instantaneous temperature changes, as when holding a cold instrument in a warm hand while calibrating. The calibrator has an adapter in the front opening to allow calibration on ½- or 1-in. microphones. Be careful that this adapter does not fall out and become lost. Use only a B&K calibrator on a B&K meter.

d. Maintenance and Repairs

The sound level meter microphone and calibrator are precision equipment and should be treated accordingly. If they fail to operate properly, return them to the Noise Measurement Unit of the Materials Bureau at the Albany Main Office, either by courier (if available) or by United Parcel Service. (Do not send by parcel post.) When shipped to the region from Albany, the equipment is accompanied by a receipt; check to be sure all that is supposed to be shipped is actually included in the package. When the equipment is returned to Albany, return the receipt, and note if any equipment was lost or broken. Keep each set of equipment together -- don't mix and match with other sets, as that makes it more difficult to keep track of equipment.

3. Test Procedure

The method to be used to determine noise levels was developed by Bolt Beranek and Newman, Inc., and is referred to as "the check-off method." The object is to provide a statistical estimate of L_{10} ± 3 dBA with 95-percent confidence. This means we can be 95-percent sure the actual L_{10} for the site is within ± 3 dBA of the L_{10} we compute from the measurements. The ± 3 dBA are termed "confidence limits" for L_{10}. The following procedure details the steps necessary to obtain acceptable measurements using this method. The measurement team will normally consist of at least two Certified NMTs. The duties of reading the meter, checking off the readings, and counting traffic should be divided between them in a way assuring that all duties are performed. For sites located near high-volume roads or intersections, other personnel may be needed to count traffic. RNLEs should be aware of such a possibility and plan accordingly.

1. Check to see that the meter is operating before going into the field. If the battery has been removed, a standard 1.5-volt size "C" cell should be inserted. An alkaline-type battery is preferred and will give up to 10 hours of meter service. To replace the battery, use a coin to unscrew the battery housing, located on the left side of the meter. Insert the battery with the positive contact outward, and replace the battery housing.

2. Obtain weather data (wind velocity, relative humidity, precipitation) and fill in appropriate information on the BR 319 cover sheet (instructions for its completion are given later in this section on p. 30). Operation of the wind meter and psychrometer were described on p. 20. The sound meter's operating temperature range is from 14 to 122 F. Discontinue operations if temperatures are lower or higher, if relative humidity exceeds 90 percent, or if wind velocity is greater than 12 mph.

3. Remove the meter from the box.

4. Turn the power switch to "batt." Check that the pointer lies within the red "batt" mark on the meter scale; if not, the battery should be replaced. Turn the meter off after the battery's condition is verified.

5. Set up the tripod. Attach the microphone extension cable between the meter and microphone, and clamp the microphone to the top of the tripod. Orient the microphone vertically 4 to 5 ft above the ground.

6. Set the range switch to a high value (above 90 dB), to avoid overloading when switching the meter on. The range switch position appears in the window on the meter scale.

7. Turn the power switch to position "slow." Unless otherwise directed, make all measurements with "slow" response.

8. Allow 1 to 2 minutes for the circuits to warm up.

9. Select Weighting Network A with the weighting network selector. Take all readings with A-weighting.

10. Calibrate the meter as described on p. 21.

11. Turn the range switch down until the meter needle reads on the scale between the range indicator window and the + 10 dB mark.

12. Estimate the range within which the noise level fluctuates and assign appropriate values to the noise level lines on the data sheet (BR 320).

13. Note starting time and at the prescribed interval (10 seconds) glance at the meter. Read the meter at that instant to avoid a biased reading. Try not to anticipate what it will be -- just note the reading as it occurs.

14. Record the A-level reading on the BR 320 data sheet as a checkmark on the appropriate horizontal decibel line, working from left to right within each line as shown on pp. 27-9.

15. Simultaneously keep count of the numbers of cars and trucks passing the measurement site if the location is close to or within sight of a highway.

16. If a disturbance occurs that is not considered representative of the existing level being measured, note it on the data sheet (BR 320).

17. After 50 readings, test them by the criteria given on p. 25. If they meet those criteria, then the measurement is complete. If not, then take another 50 readings and test them, and repeat as necessary up to a maximum of 250 readings.

18. At the conclusion of the test, re-check the calibration of the meter, re-check the battery, and record these results on Form B BR 320. If the meter is not reading 93.8 ± 0.5 dB on re-check, repeat the measurements.

19. Note the time finished and record it on the data sheet. Re-check the calculations and be sure that the data sheets are completed.

4. Sample Criteria

After each group of 50 readings, the following test is made:

1. Counting down from the top of the BR 320 data sheet (and from left to right along each line), circle the test readings shown in the following table (which is also reproduced at the top of BR 320):

Total Readings	Upper Limit	L_{10}	Lower Limit	Allowable Skew
50	1	5	10	None
100	5	10	17	1
150	8	15	23	1
200	12	20	29	1
250	16	25	35	1
300	20	30	41	1
350	25	35	47	1

For instance, after taking 50 samples, circle the first, fifth, and tenth samples from the top. These three constitute the L_{10}, flanked by its upper and lower limits.

2. The acceptable limits are ± 3 dBA or less.

3. If the 50 readings do not meet the criterion of ± 3 dB or less, then take 50 more readings in addition to the first 50. The resulting set of 100 samples is again tested for L_{10} and its ± 3 dB limits using the fifth, tenth and seventeenth samples. If 100 or more

samples have been taken, a process called skewing is allowed. By this process, the upper and lower limits can be shifted by the number of samples listed in the "Allowable Skew" column. The shift can be either up or down. For example, if the criterion is not met (after 100 samples) by the fifth, tenth, and seventeenth samples, the allowable skew according to the table is one sample. Thus the criterion can be tested with the fourth, tenth, and sixteenth samples (skewing up one sample) or with the sixth, tenth, and eighteenth samples (skewing down one sample). Although this skewing procedure will not change the L_{10} value, nor the number of samples between the upper and lower confidence limits, it can sometimes provide the necessary accuracy without requiring further sampling.

Skewing up or down on BR 320 refers to the direction of change as just explained. Note that using the fourth, tenth, and sixteenth samples from the top, instead of the fifth, tenth, and seventeenth would be skewing up, not down, and would be so entered on BR 320. Using the sixth, tenth, and eighteenth samples would be skewing down, and should be so entered.

If the criterion is still not met, even with skewing, take an additional 50 samples. The maximum to be taken at any one site is 250. If the criterion is still not met after 250 samples, note this in the "Comments" section of BR 319.

4. When the test criterion has been met (or 250 samples taken and the criterion not met), calculate L_{50} and L_{90}. The former is the noise level exceeded 50 percent of the time and is represented by the 50th percentile reading from the top. Thus with 50 readings L_{50} would be the 25th from the top, and with 100 readings the 50th from the top, and so on. L_{90} is the noise level exceeded 90 percent of the time and is represented by the 90th percentile reading from the top. L_{90} for 50 readings is the 45th from the top, and for 100 readings the 90th from the top, and so on.

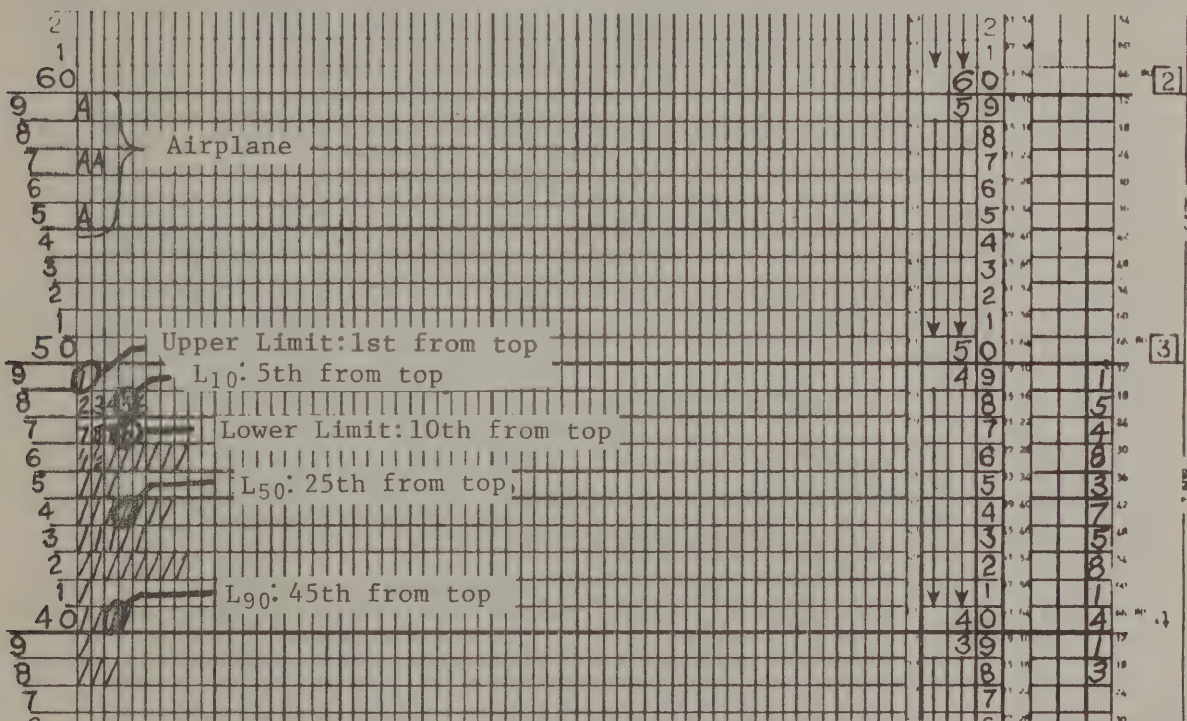
   L_{50} is counted from the top. A common mistake is to count up from the bottom of the data to find L_{90}. For example, with 100 readings, counting up to the tenth reading from the bottom will give you the 91st from the top, not the 90th.

   A simple rule in finding L_{90} is to count up from the bottom of the data the same number of readings listed under L_{10} in the table, and then count up one more -- this is L_{90}. For instance, for 150 readings, the table gives the 15th reading as L_{10}. To find L_{90}, count up from the bottom of the data 15 readings plus one.

   The examples on the next three pages should help explain these rules.

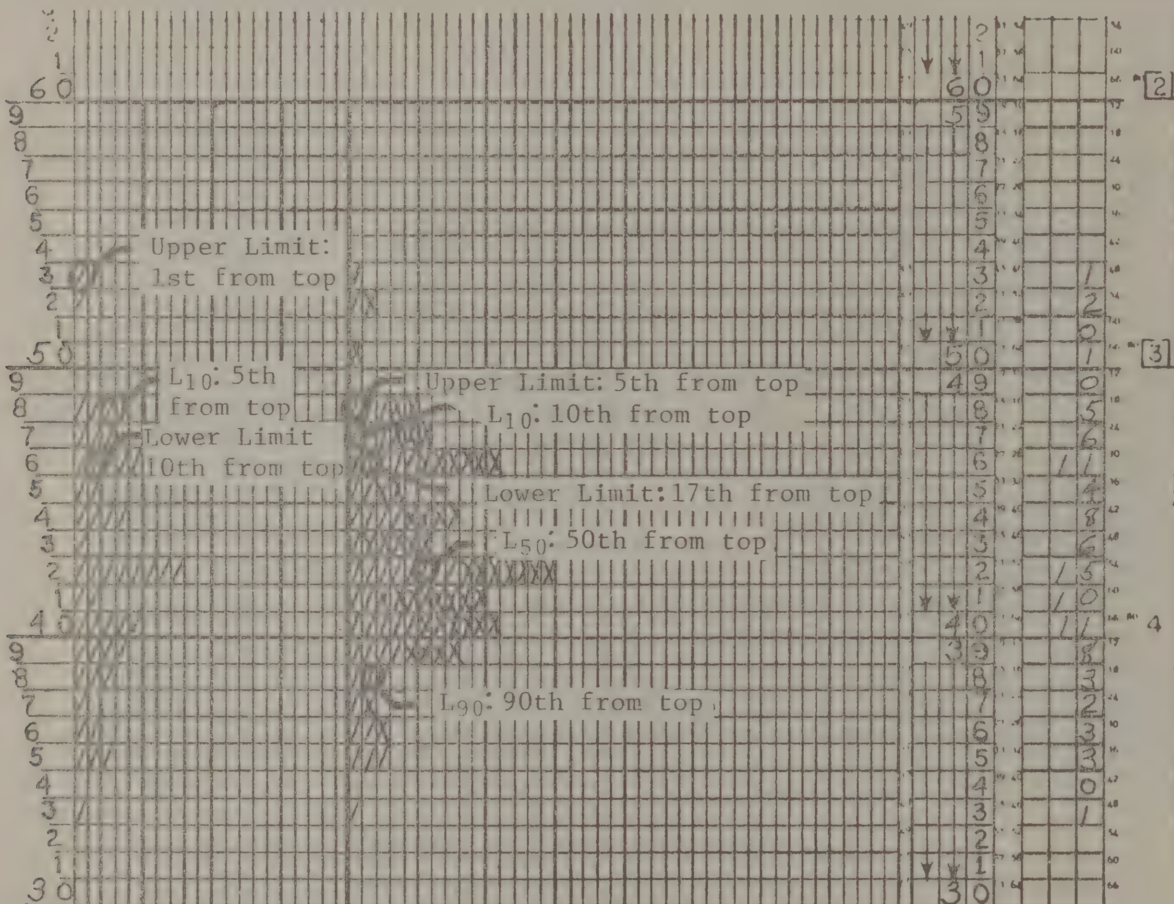
EXAMPLE 1

At this site, 50 readings were taken, ranging from 38 to 49 dB. (The four airplane readings, in this case, are not considered "representative" of the site and are not counted.) Counting down from the top, the first reading is 49 dB, the second and third both 48 dB, etc. as numbered on the sheet. In this case the fifth reading represents L_{10}, which is 48 dB. The first reading is the upper limit or 49 dB, and the tenth the lower limit at 47 dB. Since the difference between L_{10} (48 dB) and each limit is 1, L_{10} can be expressed as $48\ ^{+1}_{-1}$. No further readings are necessary, as ±1 is well within the ±3 dB limits required. L_{50} is the 25th reading from the top at 44 dB and L_{90} the 45th at 40 dB.



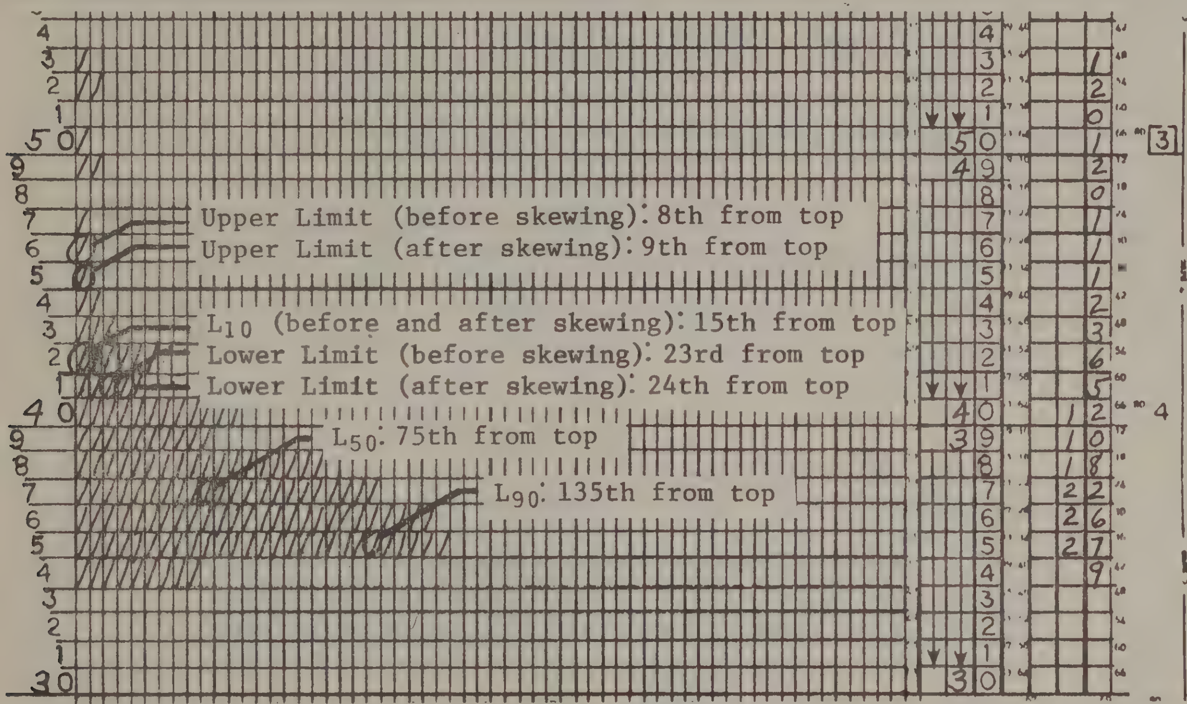
EXAMPLE 2

Here 100 samples were necessary. The first 50, represented by slashes, resulted in an L_{10} of 48^{+5}_{-2} dB (53 being the upper limit, and 46 the lower), which is not within the limits of ± 3 dB. Fifty more readings were then taken and are represented by x's. The upper limit, L_{10}, and lower limit (the 5th, 10th, and 17th readings) are now 48, 47, and 46 dB, respectively. The L_{10} limits ($47\ ^{+1}_{-1}$ dB) are now within requirements.



EXAMPLE 3

In this case, 150 readings were taken. The upper limit, L_{10}, and lower limit are 46 dB (8th from the top), 42 dB (15th from the top), and 41 dB (23rd from the top). These data can be skewed down by shiftin the upper limit to 9th from the top (44 dB), and the lower limit to 24th from the top (still 41 dB). L_{10} remains 42 dB and is now 42^{+3}_{-1} instead of 42^{+4}_{-1}.



5. Noise Data Forms

The two forms the NMT team will be concerned with are the Noise Measurement Cover Sheet (BR 319) and the Noise Measurement Data Sheet (BR 320). The first contains common identifying information that remains the same for a number of test sites. This information can be coded just once on a cover sheet, which can represent up to eight measurement sites. The second is for recording actual test data; the coded tallies of measurements; the L_{10}, L_{50}, and L_{90} values; and other information unique to a particular test site. The BR 319 and 320 comprise the hard copy of the noise measurement field data required by PPM 90-2. They will be used to transmit these data to the Main Office Noise Unit for keypunching and entry into the permanent Electronic Data Processing (EDP) Bureau computer file.

Information for keypunching must be written neatly and accurately. One character should be entered in each box provided. Use no special characters, roman numerals, or punctuation. Allowable characters include capital letters A through Z and the numbers 0 through 9. To differentiate between the letter O (oh) and the number 0 (zero), place a slash through the letter in this manner: Ø.

a. General Rules for Coding Forms

1. Enter only one character (letter or number) in each box.

   Example: For May 8, 1976 Date (Month) 05 / (Day) 08 / (Year) 76

2. Decimals are printed on the forms; print only numbers in the boxes.

   Example: PIN 4218.12.000

3. Always record numbers from right to left in each group of boxes.

   Example: Enter a single digit as follows 006

4. If an error occurs, draw a horizontal line through the entry, and record the correct data above the boxes involved.

   Example: 3040 ~~3004~~

5. If an item is incorrectly circled, draw a diagonal line through the error and circle the correct item.

   Example: Skew

none	↑	↓
0	~~1~~	2

6. Record starting and finishing times for each measurement on both the cover sheet and the data sheet. Be sure time is the same on both. Record times in 24-hour fashion.

   Example: For 3:45 p.m. 15:45

7. Enter a slash through the letter "O" to distinguish it from a zero.

   Example: | S | Ø | U | T | H |

b. <u>Specific Rules for Coding the Cover Sheet (BR 319)</u>.

This form has two sections. The first five lines identify the project. The entries intended are those providing the best available information.

1. If the project has a PIN, include it.

2. If a site or group of sites are near (within about 1000 ft) a state highway reference marker, list it. Three groups of boxes are provided; in the first group, the fourth box is reserved for the <u>letter</u> (if any) in the top line on the reference marker, but if none appears on the marker, leave the fourth box blank.

   Example: For a marker reading 9A / 8701 / 1625 enter as follows

   | 0 | 0 | 9 | A | | 8 | 7 | 0 | 1 | | 1 | 6 | 2 | 5 |

3. If the site is near (within about 1000 ft) an interstate or state highway, with or without a reference marker nearby, list the route number. The single box to the right of "Nearest State Rte." is reserved for the <u>letter</u> prefix or suffix, if any, associated with that route number; if it has none, leave the box blank.

Examples:	For Route 9A	009	A
	For Route 28	028	
	For I 787	787	I

4. If the site is in the vicinity of a town or county road or a local street, or if the state highway discussed in the two previous paragraphs has a local name, enter that information in the "Road/Street" boxes.

5. If the site cannot be described in any of the ways already listed, use the nearest identifiable major landmark, whether natural or manmade. Landmarks may be rivers or streams, lakes, railroads, parks, schools, hospitals, or other easily located permanent features.

   Example: | S | T | | M | A | R | Y | | H | Ø | S | P |

6. Always list the official name of the city, village, or town, and the county name in locating each group of sites.

The balance of the cover sheet, after these five lines describing the project where measurements are to occur, gives details of the conditions under which they occur.

1. Each cover sheet can be used to provide information for up to eight measurement sites or "points," including re-tests.

2. Each site is represented by a "point number." If more than one measurement is made at a site, its point number does not change.

3. Record the starting and finishing times of each measurement on both the cover and the data sheets. Be sure the times are the same on both sheets.

4. Indicate in the "Notes" section any special circumstances or events that might affect the data.

c. Specific Rules for Coding the Data Sheet (BR 320)

1. At the lower right, fill in the manufacturer's meter serial number, initial calibration, battery check, date, PIN, weighting, response, test interval, precipitation, wind velocity, time started (on a 24-hour clock), and point number.

2. On the grid portion of the form, estimate the range in which the data readings will fall, assign the appropriate values to the check-off rows on the far left of the grid, and fill in the coding boxes to the right of the check-off section to indicate the noise level represented by each row.

3. Collect the data.

4. Indicate in the "Tally" column at the far right of the form the total number of occurrences for each dB level having at least one occurrence.

5. Circle the check marks for the occurrences representing the L_{10}, L_{50}, and L_{90} levels and the adjusted upper and lower confidence limits for the L_{10} level, as shown in the examples (pp. 27-29).

6. Complete the specific site information and measurement results located at the bottom of this form according to the general coding rules given previously, and draw a diagram of the site with dimensions.

When the field work is completed for a project, the RNLE will send the white original cover sheet and the associated white original data sheets (originals being required by the Main Office EDP Bureau for keypunching), along with a map showing the locations of sites actually measured in the field, to the Main Office Noise Measurement Unit.

6. Special Considerations

General sites for noise measurements will usually be chosen and located on a map by a design or planning engineer. The technician team then takes the map to the sites and picks the best location to set up equipment. If the site of interest is near a house or school, place the meter in the yard where there is likely to be human activity. The object is to measure noise from all sources to which the occupant is normally exposed -- not just traffic noise. Therefore, the meter should not be set up next to the road, where traffic noise is dominant. Also avoid billboards, sides of buildings, and other large reflecting surfaces. Noise tends to be reflected back to the microphone, increasing the noise level. It is sometimes necessary, however, to locate near a reflective surface; this should be done if so specified by the RNLE.

Sometimes it is difficult to determine whether a sound is characteristic of a site. For example, an airplane may fly over during a measurement period. Perhaps only one flies over each day and you caught it, or perhaps they fly over frequently. In the former case, note the readings, but don't use them for calculating L_{10}. In the latter, count the airplane as typical noise. A tractor operating on a fram might be considered typical noise, but one should try to return to the site to measure when it is not operating. In any event, the fact that a tractor was operating should be noted on the cover sheet.

As for when to measure, we are limited to whenever the technician team gets to the site. It is impractical to try to hit each site when it is noisiest. Rush-hour traffic is not necessarily the noisiest condition -- heavy truck traffic may not appear until night-time. The best we can do is to project noise levels from measurements accompanied by traffic counts. The fine points of site selection, disturbances, and other measurement-related problems are often left to the discretion of the NMT team. In an unusual situation, however, the RNLE should be consulted to resolve the problem. Additional support may be obtained (calling collect, if necessary) from the Main Office Noise Unit in Albany; use the state tie-line access code or Area Code 518, and then dial 457-4285. This unit is also interested in your comments on special problems and their resolution.

7. Noise Measurement Technician's Checklist

a. Equipment

1. Sound level meter with microphone.
2. Calibrator.
3. Windscreen.
4. Wind velocity meter.

5. Extension cable.
6. Tripod.
7. Clipboard and counter.
8. Sling psychrometer.
9. Stopwatch.
10. Spare batteries.

b. Procedure

1. Check that the meter is operating before going into the field.
2. Measure and record wind speed -- do not take noise measurements if the wind is over 12 mph. Check relative humidity twice a day; discontinue operations if it exceeds 90 percent. Discontinue noise measurements if the temperature falls below 14 F or exceeds 122 F.
3. Check the meter battery.
4. Set up the meter, tripod, and extension cable.
5. Calibrate the meter -- 93.8 dB before measuring -- and re-check it after each site measured. Repeat the measurment if it is not registering in that range.
6. Take noise readings using A-weighting and slow response. Note starting time.
7. Calculate L_{10}, L_{50}, and L_{90}. Note finishing time.
8. Fill out the data sheet completely before leaving the site.
9. Have your partner check your calculations.

APPENDIX

A. Glossary of Terms
B. Forms List
C. Equipment List
D. Method of Determination of Confidence Limits and Coefficients
E. References for Further Reading
F. Mathematical Statement of Sound Pressure Level and Decibel
   Addition of Two Equal Sources
G. FHWA Policy and Procedure Memorandum 90-2

A. Glossary of Terms

A-Weighting: adjustment of the amplitude of a sound wave based on frequency designed to approximate frequency response of the human ear.

Ambient Noise: all noise existing at a site.

Amplitude: for a wave, the amount of displacement from an equilibrium level.

Attenuation: a reduction of wave amplitude.

Calibrator: an electronic device used to generate a known sound level.

Car: any four-tire, two-axle vehicle, including sports cars, pickup trucks, and small vans.

Characteristic Sound: a sound representative of a measurement site.

Check-off Method: a method for measuring ambient noise by taking readings at a prescribed time interval, ranking them, and analyzing them statistically.

Confidence Limits: the upper and lower values of the range within which a given percent probability applies; for instance, if the chances are 95 out of 100 that a sample lies between 10 and 12, the 95-percent confidence limits are said to be 10 and 12.

Cycle per Second: a complete wave occurring in 1 second (see Hertz).

Data: measurements taken as bases for an investigation.

dB: abbreviation for decibel.

dBA: abbreviation for decibel utilizing the A-weighting network.

Decibel: the units of amplitude measurement for sound pressure level, defined as

$$SPL_{dB} = 10 \log \left(\frac{P}{P_0}\right)^2 \quad \text{or} \quad SPL_{db} = 20 \log \left(\frac{P}{P_0}\right)$$

where P = disturbance pressure, and

P_0 = reference pressure.

Equilibrium Level: the reference or undisturbed level for a particular quantity; for sound, the equilibrium level is atmospheric pressure.

Frequency: the number of time a wave repeats within a given period.

Hertz: one cycle per second, abbreviated Hz.

Humidity: the percent of moisture in the air.

L_{10}, L_{50}, L_{90}: sound levels exceeded, respectively, 10, 50, and 90 percent of the time.

Logarithm: the power to which a base number is raised to equal a given value; for example, $10^2 = 100$ and $\log_{10} 100 = 2$.

Masking: the effect whereby a sound that is approximately 10 dB or greater than another "drowns out" the lesser sound.

Microphone: an electronic device sensitive to pressure changes, converting them into electrical current.

Noise: unwanted sound.

Pressure: force applied on a given area; some pressure units are pounds per square inch (psi), atmospheres, etc.

Reference Pressure: for sound measurement, this is 20 micronewtons per square meter; -- the smallest pressure the ear can detect.

Sling psychrometer: a device for measuring relative humidity.

Sound: a wave disturbance in an elastic medium, such as air.

Sound Level: weighted sound pressure level measured by a metering device.

Sound Level Meter: a device for measuring sound level.

Sound Pressure Level: in decibels, 10 times the logarithm of the square of the ratio of the disturbance pressure to the reference pressure; it is a measure of the amplitude of a sound wave.

Traffic Mix: percentage of cars and trucks in the total number of vehicles.

Traffic Volume: total number of vehicles in a given time period.

Wave: variation in a medium characterized by frequency and amplitude.

Windscreen: a porous polyurethane sponge material used on a microphone to eliminate wind noise and protect against dust.

Wind Velocity Meter: a device for measuring wind speed.

B. Forms List

1. Form BR 319: Noise Measurement Cover Sheet.

2. Form BR 320: Noise Measurement Data Sheet.

C. Equipment List

1. Brüel and Kjaer Type 2206 Sound Level Meter with Type 4148 Condenser Microphone.

2. Brüel and Kjaer Type 4230 Calibrator.

3. Windscreen.

4. Wind Velocity Meter.

5. Extension cable.

6. Tripod.

7. Clipboard with counter.

8. Sling Psychrometer.

9. Stopwatch.

10. Spare Batteries.

D. Method of Determination of Confidence Limits and Coefficients

This method is reproduced in facsimile from Fundamentals and Abatement of Highway Traffic Noise (see Anderson, Miller, and Shadley in Appendix E).

Assume that a total of n statistically independent noise levels l have been measured from the same population. Assume, further, that these noise levels are ordered according to their magnitudes, and let the sequence of these ordered levels be denoted by l_1, $l_2, \ldots l_n$, where the highest measured level is denoted by l_1 and the lowest is denoted by l_n.

Let L_p denote the p*th* percentile noise level as determined by the infinite population from which the n samples have been drawn. L_p is defined by,

$$\int_{L_p}^{\infty} f(l)\,dl = p, \tag{1}$$

where $f(l)$ is the probability density function of the noise levels from which the samples have been drawn. Thus, the probability is p that a randomly drawn sample will have a level l higher than the level L_p. The problem is to estimate L_p, for a given value of p, from a finite set of ordered samples l_1, $l_2, \ldots, l_n$.

Assume that n samples have been drawn and ordered as described above. Consider the event $l_r > L_p > l_s$ where $r < s$; that is, the event that the r*th* noise level is higher than L_p and the s*th* noise level is lower than L_p. This event is equivalent to the compound event that exactly r measured levels are higher than L_p *or* exactly r+1 measured levels are higher than L_p *or* ... *or* exactly s-2 measured levels are higher than L_p *or* exactly s-1 mea-

sured levels are higher than L_p. These events are mutually exclusive; therefore, the probability of this compound event is the sum of the probabilities of the individual events. Now, according to Eq. 1, the probability is p that any one noise level measurement is larger than L_p. Since the measured levels are assumed statistically independent, the probability that exactly k of the measured levels are higher than L_p is the probability of exactly k "successes" in a set of n Bernoulli trials, where the probability of the "success" of a single trial is p. In such a situation, the probability of k successes is

$$\binom{n}{k} p^k (1-p)^{n-k} , \tag{2}$$

where

$$\binom{n}{k} = \frac{n!}{(n-k)!k!} . \tag{3}$$

Thus, the probability of the above described compound event is obtained by summing the probabilities (2) for k=r, r+1, ..., s-2, s-1;

that is

$$Pr\left|l_r > L_p > l_s\right| = \sum_{k=r}^{s-1} \binom{n}{k} p^k (1-p)^{n-k} \tag{4}$$

Equation 4 expresses the probability that at least r but less than s noise level measurements fall above the level L_p. Notice that at no point have we made any assumptions about the form of the noise level probability density function $f(l)$.

Let us now designate Pr $\left[l_r > L_p > l_s\right]$ by γ; i.e.,

$$Pr\left[l_r > L_p > l_s\right] = \gamma . \tag{5}$$

Then, by definition, γ is the confidence coefficient that the *rth* and *sth* measured levels satisfy the relationship $l_r > L_p > l_s$; l_r and l_s are known as the upper and lower confidence limits for the *pth* percentile noise level L_p.

Table 3.1 lists values of γ for selected sets of values of n, r, and s, where all values listed are for the case where p = 0.10. The values were computed using the right-hand side of Eq. 4.

TABLE 3.1 - CONFIDENCE COEFFICIENTS

Number of Samples, n	Lower Error Limit, r	Upper Error Limit, s	Confidence Coefficient, γ
350	24	46	0.949
350	25	47	0.950
350	26	48	0.944
300	19	40	0.952
300	20	41	0.957
300	21	42	0.955
250	15	34	0.950
250	16	35	0.956
250	17	36	0.952
200	11	28	0.949
200	12	29	0.956
200	13	30	0.952
150	7	22	0.950
150	8	23	0.960
150	9	24	0.955
100	4	16	0.952
100	5	17	0.956
100	6	18	0.932
50	1	10	0.970
50	2	10	0.942

E. References for Further Reading

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Journal of Sound and Vibration, Academic Press, 111 Fifth Ave., New York, N.Y. 10003.

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F. Mathematical Statement of Sound Pressure Level And Decibel Addition of Two Equal Sources

The mathematical statement of sound pressure level in decibels is

$$SPL_{dB} = 20 \log_{10} \frac{P}{P_0}$$

where P = the change from atmospheric pressure caused by the sound wave, and

P_0 = the reference pressure, equal to the smallest pressure the human ear can detect.

As stated earlier, the range of pressures the human ear can detect is very large. Because this is true, the logarithm of the pressure ratio is used. By using a logarithm, we can convert a very large number into a much smaller one. We can then convert the very large range of pressures the human ear can detect into a smaller range of numbers that are easier to deal with, thus making it easier to compare different sounds.

For instance, suppose we had four sound waves, each causing a pressure disturbance 10 times greater than the previous one. In mathematical terms, we couls state this as follows:

Sound Wave 1: $P_1 = 100\ P_0$

Sound Wave 2: $P_2 = 10\ P_1 = 1{,}000\ P_0$

Sound Wave 3: $P_3 = 10\ P_2 = 10{,}000\ P_0$

Sound Wave 4: $P_4 = 10\ P_3 = 100{,}000\ P_0$

Dividing both sides of these equations by P_0, we get:

$$\frac{P_1}{P_0} = 100 \frac{P_0}{P_0} = 100$$

$$\frac{P_2}{P_0} = 1000 \frac{P_0}{P_0} = 1{,}000$$

$$\frac{P_3}{P_0} = 10{,}000 \frac{P_0}{P_0} = 10{,}000$$

$$\frac{P_4}{P_0} = 100{,}000 \frac{P_0}{P_0} = 100{,}000$$

since dividing P_0 by P_0 is equal to 1, just as 2 divided by 2, or 3 divided by 3 equals 1.

Now, SPL is defined in terms of "base 10" logarithms. This means we know that 10 x 10 = 100 -- 10 x 10 is known as 10^2 (10 squared). Similarly, 10 x 10 x 10 = 1,000 = 10^3 (10 cubed). The "base 10" logarithm of a number is defined as the number of times 10 must be multiplied by itself to get the number. For instance,

$$10 \times 10 = 100$$

or

$$10^2 = 100$$

Then

$$\log_{10} 100 = 2$$

Ten multiplied by itself will give 100. Therefore, the base 10 logarithm of 100 is equal to 2. In the same way, then, if $\log_{10} 100 = 2$, then

$$\log_{10} 1{,}000 = 3 \quad (10 \times 10 \times 10 = 1000)$$

Similarly,

$$\log_{10} 10{,}000 = 4 \quad (\underset{1}{10} \times \underset{2}{10} \times \underset{3}{10} \times \underset{4}{10} = 10{,}000)$$

$$\log_{10} 100{,}000 = 5 \quad (\underset{1}{10} \times \underset{2}{10} \times \underset{3}{10} \times \underset{4}{10} \times \underset{5}{10} = 100{,}000)$$

Let's return to our sound waves. The SPL equation says we multiply 20 times the base 10 logarithm of P/P_0. Setting up a table:

Sound Wave	P/P_0	$\log_{10} P/P_0$	SPL_{db}
1	100	2	40
2	1,000	3	60
3	10,000	4	80
4	100,000	5	100

We can see that for a range of pressures from 100 to 100,000 times the smallest pressure the ear can detect, the range in decibels is only 40 to 100. It is much easier to compare numbers from 40 to 100, and plot 40 to 100 on a graph or measuring device, than to plot 100 to 100,000.

Now, as we also said earlier, if two boards are each 10 ft long, the total length of both is 20 ft. However, two equal sound sources producing 70 dB each add up to only 73 dB -- not 140 dB. This is because:

the definition of SPL is decibels is:

$$SPL_{dB} = 20 \log_{10} \frac{P}{P_0}$$

this is the same as

$$SPL_{dB} = 10 \log_{10} \left(\frac{P}{P_0}\right)^2$$

where

$$\left(\frac{P}{P_0}\right)^2 = \frac{P}{P_0} \times \frac{P}{P_0}$$

To prove this, let's assume $P/P_0 = 100$. Then

$$\left(\frac{P}{P_0}\right)^2 = \frac{P}{P_0} \times \frac{P}{P_0} = 100 \times 100 = 10{,}000$$

Lets put the two equations for SPL side by side:

$SPL_{dB} = 20 \log_{10} \frac{P}{P_0}$	$SPL_{dB} = 10 \log_{10} \left(\frac{P}{P_0}\right)^2$
$SPL_{dB} = 20 \log_{10} 100$	$SPL_{dB} = 10 \log_{10} 10{,}000$
$\log_{10} 100 = 2$	$\log_{10} 10{,}000 = 4$
$10 \times 10 = 100$	$10 \times 10 \times 10 \times 10 = 10{,}000$
$\therefore SPL_{dB} = 20 \times 2$	$\therefore SPL_{dB} = 10 \times 4$
$SPL_{dB} = 40$	$SPL_{dB} = 40$

We can see then that both definitions are the same because they produce the same answer. Let's get back now to our two equal sound sources. Suppose the pressure ratio produced by one source is $(P/P_0) = 10$. Then

$$\left(\frac{P}{P_0}\right)^2 = \frac{P}{P_0} \times \frac{P}{P_0}$$

$$= 10 \times 10$$

$$= 100$$

For two equal sources, the pressure ratio squared will be twice this, or

$$2\left(\frac{P}{P_0}\right)^2 = 200$$

$$SPL_{\text{one source}} = 10 \log_{10} \left(\frac{P}{P_0}\right)^2$$

$$\left(\frac{P}{P_0}\right)^2 = 100$$

$$SPL_{\text{one source}} = 10 \log_{10} 100$$

$$\log 10 = 2$$

$$\therefore SPL_{\text{one source}} = 10 \times 2$$

$$SPL_{\text{one source}} = 20 \text{ dB}$$

$$SPL_{\text{two equal sources}} = 10 \log_{10} 2 \left(\frac{P}{P_0}\right)^2$$

$$2 \left(\frac{P}{P_0}\right)^2 = 200$$

$$SPL_{\text{two equal sources}} = 10 \log_{10} 200$$

$$\log_{10} 200 = 2.3$$

(The base 10 log of 200 can be found in any table of logarithms)

$$\therefore SPL_{\text{two equal sources}} = 10 \times 2.3$$

$$SPL_{\text{two equal sources}} = 23 \text{ dB}$$

Thus two equal sources produce only a 3-dB increase in SPL over only one of the sources.

G. FHWA Policy and Procedure Memorandum 90-2

U.S. DEPARTMENT OF TRANSPORTATION FEDERAL HIGHWAY ADMINISTRATION POLICY AND PROCEDURE MEMORANDUM	Transmittal 279 90-2 February 8, 1973
NOISE STANDARDS AND PROCEDURES	

1. PURPOSE

To provide noise standards and procedures for use by State highway agencies and the Federal Highway Administration (FHWA) in the planning and design of highways approved pursuant to Title 23, United States Code, and to assure that measures are taken in the overall public interest to achieve highway noise levels that are compatible with different land uses, with due consideration also given to other social, economic and environmental effects.

2. AUTHORITY

Sections 109(h) and (i), Title 23, United States Code, state that guidelines shall be promulgated "to assure that possible adverse economic, social, and environmental effects relating to any proposed project on any Federal-aid system have been fully considered in developing such project, and that the final decisions on the project are made in the best overall public interest, taking into consideration the need for fast, safe and efficient transportation, public services, and the costs of eliminating or minimizing such adverse effects and the following: (1) air, noise, and water pollution; . . ." and that "The Secretary, after consultation with appropriate Federal, State, and local officials, shall develop and promulgate standards for highway noise levels compatible with different land uses and after July 1, 1972, shall not approve plans and specifications for any proposed project on any Federal-aid system for which location approval has not yet been secured unless he determines that such plans and specifications include adequate measures to implement the appropriate noise level standards."

3. NOISE STANDARDS

a. Noise standards are appended as Appendix B. Federal Highway Administration encourages application of the noise standards at the earliest appropriate stage in the project development process.

b. There may be sections of highways where it would be impossible or impracticable to apply noise abatement measures. This could occur where abatement measures would not be feasible or effective due to physical conditions, where the costs of abatement measures are high in relation to the benefits achieved, or where the measures required to abate the noise condition conflict with other important values, such as desirable esthetic quality, important ecological conditions, highway safety, or air quality. In these situations, highway agencies should weigh the anticipated noise impacts together with other effects against the need for and the scope of the project in accordance with other FHWA directives (PPM's 20-8, 90-1, and 90-4).

4. APPLICABILITY

In order to be eligible for Federal-aid participation, all projects to which the noise standards apply shall include noise abatement measures to obtain the design noise levels in these standards unless exceptions have been approved as provided herein.

a. Projects to which noise standards apply. The noise standards apply to all highway projects planned or constructed pursuant to Title 23, United States Code, except projects unrelated to increased traffic noise levels, such as lighting, signing, landscaping, safety and bridge replacement. Pavement overlays or pavement reconstruction can be considered as falling within this category unless the new pavement is of a type which produces more noise than the type replaced.

b. Approvals to Which Compliance with Noise Standards Is Prerequisite

(1) Projects for which location was approved prior to July 1, 1972: Compliance

with noise standards shall not be a prerequisite to any subsequent approval provided design approval is secured prior to July 1, 1974. If design approval is not secured for such a project prior to July 1, 1974, compliance with the noise standards shall be a prerequisite to securing both design approval and approval of plans and specifications. However, such compliance shall not be a basis for requiring reconsideration of the highway location or any other approval action which has previously been taken for such projects.

(2) Projects for which location is approved on or after July 1, 1972:

(a) If location approval was requested on or before December 31, 1972, compliance with the noise standards shall be a prerequisite to obtaining design approval and approval of plans and specifications. Compliance with the noise standards shall not be a prerequisite to obtaining location approval, nor shall such compliance be a basis for requiring reconsideration of the highway location or any other approval action which has previously been taken for such projects. Combined location and design approval shall be handled in the same manner as separate design approval.

(b) If location approval is requested after December 31, 1972, compliance with the noise standards shall be a prerequisite to obtaining location and design approvals as well as approval of plans and specifications.

5. PROCEDURES

The noise standards should be implemented at the earliest appropriate stage in the project development process. These procedures have been developed accordingly:

a. Project Development. A report on traffic noise will be required during the location planning stage and the project design stage. The reports may be sections in the location and design study reports, or they may be separate. The procedures for noise analysis, identification of solutions, coordination with local officials, and incorporation of noise abatement measures are as follows:

(1) Nonapplicable Projects. If a State highway department determines (in accordance with paragraph 4a) that noise standards do not apply to a particular project, the requests for location approval and design approval shall contain statements to that effect, including the basis on which the State made its determination.

(2) Noise Analysis. For applicable projects, analyses of noise and evaluation of effects are to be made during project development studies using the following general steps:

(a) Predict the highway-generated noise level as described in the standards for each alternative under detailed study.

(b) Identify existing land uses or activities which may be affected by noise from the highway section.

(c) By measurement, determine the existing noise levels for developed land uses or activities.

(d) Compare the predicted noise levels with the design level values listed in the standards. Also compare the predicted noise levels with existing noise levels determined in paragraph 5a(2)(c). These comparisons will be the basis for determining the anticipated impact upon land uses and activities.

(e) Based upon the noise impacts determined in paragraph 5a(2)(d), evaluate alternative noise abatement measures for reducing or eliminating the noise impact for developed lands.

(f) Identify those situations where it appears that an exception to the design noise levels will be needed. Prepare recommendations to be included in the traffic noise report. (This report may be a portion of the location and design study reports or it may be a separate report.)

(3) Location Phase and Environmental Impact Statement Requirements. To the extent this PPM is applicable to the location phase of projects under paragraph 4, the noise report shall describe the noise problems which may be created and the plans for dealing with such problems for each alternative under detailed study. The level of detail of the noise analysis in the location phase should be consistent with the level of detail in which the location study itself is made. This information including a preliminary discussion of exceptions anticipated, shall be set forth in the location study report and summarized in the environmental impact statement (if one is prepared) and, as appropriate, at the location hearing (for location hearings after December 31, 1972). Studies and reports for highway locations approved before December 31, 1972, need not include an analysis and report on noise. In such instances, the noise analysis and report will be required only for the design approval.

(4) Design Phase Requirements. The noise analysis prepared for the location phase is to be updated and expanded using the refined alignment and design information developed during the design studies. The report on traffic noise will include a detailed analysis of the anticipated noise impact, alternative or proposed abatement measures, discussion of coordination with local officials, and recommended exceptions.

(5) Coordination with Local Officials on Undeveloped Lands. Highway agencies have the responsibility for taking measures that are prudent and feasible to assure that the location and design of highways are compatible with existing land use. Local governments, on the other hand, have responsibility for land development control and zoning. Highway agencies can be of considerable assistance to local officials in these efforts with a view toward promoting compatibility between land development and highways. Therefore, for undeveloped lands (or properties) highway agencies shall cooperate with local officials by furnishing approximate generalized future noise levels for various distances from the highway improvement, and shall make available information that may be useful to local communities to protect future land development from becoming incompatible with anticipated highway noise levels.

(6) Noise Abatement Measures for Lands Which are Undeveloped at Time of Location Approval

(a) Noise abatement measures are not required for lands which are undeveloped at the time of location approval; however, the highway agency may incorporate noise abatement measures for such undeveloped lands in the project design (if approved by FHWA) when a case can be made for doing so based on consideration of anticipated future land use, future need, expected long term benefits, and the difficulty and increased cost of later incorporating abatement measures.

(b) For land uses or activities which develop after location approval, noise abatement measures should be considered for incorporation in the project in the following situations:

1 It can be demonstrated that all practicable and prudent planning and design were exercised by the local government and the developer of the property to make the activity compatible with the predicted noise levels which were furnished to the local government and especially that a considerable amount of time has elapsed between location approval and highway construction thus limiting local government's ability to maintain control over adjoining land uses.

2 The benefits to be derived from the use of highway funds to provide noise abatement measures is determined to outweigh the overall costs.

3 The noise abatement measures can be provided within the highway's proposed right-of-way or wider rights-of-way or easements acquired for that purpose.

(c) There are some situations where the design noise levels should be applied to lands which are undeveloped at the time of location approval. Some of these instances occur where the development of new land uses or activities is planned at the same time as the highway location studies. Other instances occur where planning for the new development has preceded the highway location studies but the development has been delayed. These types of situations should be treated as though the land use or activity were in existence at the time of location approval provided:

1 The State highway agency is apprised of such prior planning.

2 The construction of the new land use or activity is started prior to highway construction or there is good reason to believe that it will start before highway construction.

(7) Incorporation of Noise Abatement Measures in Plans and Specifications. For those projects to which the standards apply, the plans and specifications for the highway section shall incorporate noise abatement measures to attain the design noise levels in the standards, except where an exception has been granted.

(8) Requests for Exceptions. Requirements and supporting materials for requests for exceptions to the design noise levels are described in paragraph 2 of Appendix B to this PPM. To the extent possible, consistent with the level of detail of the location study, identifiable exceptions should be reported in the location study report. The request for location approval shall contain or be accompanied by a request for approval of exceptions that have been identified in the location stage. Supporting material may be contained in the location study report. Subsequent requests for review and approval of additional exceptions, if any, will be similarly processed in conjunction with design approval.

b. Federal Participation

(1) Shifts in alignment and grade are design measures which can be used to reduce noise impacts. The following noise abatement measures may also be incorporated in a project to reduce highway-generated noise impacts. The costs of such measures may be included in project costs.

(a) The acquisition of property rights (either in fee or a lesser interest) for providing buffer zones or for installation or construction of noise abatement barriers or devices.

(b) The installation or construction of noise barriers or devices, whether within the highway right-of-way or on an easement obtained for that purpose.

(2) In some specific cases there may be compelling reasons to consider measures to "sound-proof" structures. Situations of this kind may be considered on a case by case basis when they involve such public or non-profit institutional structures as schools, churches, libraries, hospitals, and auditoriums. Proposals of this type, together with the State's recommendation for approval, shall be submitted to FHWA for consideration.

c. Approval Authority

(1) Exceptions to the Design Noise Levels. The FHWA Division Engineer is authorized to approve exceptions to the design noise levels and alternate traffic characteristics for noise prediction as provided in paragraph 3b, Appendix B.

(2) Noise Prediction Method. Noise levels to be used in applying the noise standards shall be obtained from a prediction method approved by FHWA. The noise prediction method contained in National Cooperative Highway Research Program Report 117 and the method contained in Department of Transportation, Transportation Systems Center Report DOT-TSC-FHWA-72-1 are approved as of the date of this issue for use in applying the noise standards. Other noise prediction methods or variations of the above should be furnished to the FHWA Office of Environmental Policy together with supporting and validation information for approval.

R. R. Bartelsmeyer

R. R. Bartelsmeyer
Acting Federal Highway Administrator

DEFINITIONS (As used in this PPM)

Design Approval - the approval (described in PPM 20-8) given by the Federal Highway Administration (FHWA) (at the request of a State highway department) based upon a design study report and a design public hearing or opportunity therefor. This action establishes FHWA acceptance of a particular design and is prerequisite to authorization of right-of-way acquisition and construction.

Design Noise Level - the noise levels established by the noise standards set forth herein for various land uses or activities to be used for determining traffic noise impacts and the assessment of the need for and type of noise abatement treatment for a particular highway section.

Design Year - the future year used to estimate the probable traffic volume to be used as one of the primary bases for the roadway design. A time 20 years from construction is common for multilane and other major projects. Periods of 5 or 10 years are not uncommon for low volume roads.

Developed Land Uses or Activities - those tracts of land or portions thereof which contain improvements or activities devoted to frequent human use or habitation. The date of issue of a building permit (for improvements under construction or subsequently added) establishes the date of existence. Park lands in categories A and B of Table 1, Appendix B, include all such lands (public and private) which are actually used as parks on the date the highway location is approved and those public lands formally set aside or designated for such use by a governmental agency. Activities such as farming, mining, and logging are not considered developed activities. However, the associated residences could be considered as a developed portion of the tract.

Highway Section - a substantial length of highway between logical termini (major crossroads, population centers, major traffic generators, or similar major highway control elements) as normally included in a single location study.

L_{10} - the sound level that is exceeded 10 percent of the time (the 10th percentile) for the period under consideration. This value is an indicator of both the magnitude and frequency of occurrence of the loudest noise events.

Level of Service C - traffic conditions (used and described in the Highway Capacity Manual-Highway Research Board, Special Report 87) where speed and maneuverability are closely controlled by high volumes, and where vehicles are restricted in freedom to select speed, change lanes, or pass.

Location Approval - the approval (described in PPM 20-8) given by the FHWA (at the request of a State Highway Department) based upon a location study report and a corridor public hearing or opportunity therefor. This action establishes a particular location for a highway section and is prerequisite to authorization to proceed with the design. (Concurrent location and design approval is sometimes given for projects involving upgrading existing roads. In these instances, location approval is not a prerequisite to authorization of design.)

Noise Level - the weighted sound pressure level obtained by the use of a metering characteristic and weighting A as specified in American National Standard Specification S1.4-1971. The abbreviation herein used is dBA.

Operating Speed - the highest overall speed at which a driver can travel on a given highway under favorable weather conditions and under prevailing traffic conditions without at any time exceeding the safe speed as determined by the design speed on a section-by-section basis.

Project Development - studies, surveys, coordination, reviews, approvals, and other activities normally conducted during the location and design of a highway project.

Truck - a motor vehicle having a gross vehicle weight greater than 10,000 pounds and buses having a capacity exceeding 15 passengers.

NOISE STANDARDS

1. Design Noise Level/Land Use Relationship

a. The design noise levels in Table 1 (page B-4) are to be used during project development of a highway section to determine highway traffic noise impacts associated with different land uses or activities in existence at the time of location approval. In addition, the table is to be used to determine the need for abatement measures for traffic generated noise for developed land uses and activities in existence at the time of location approval. Exceptions to the design noise levels may be granted on certain types of highway improvements or portions thereof when the conditions outlined in paragraph 2 are met.

b. The exterior noise levels apply to outdoor areas which have regular human use and in which a lowered noise level would be of benefit. These design noise level values are to be applied at those points within the sphere of human activity (at approximate ear level height) where outdoor activities actually occur. The values do not apply to an entire tract upon which the activity is based, but only to that portion in which the activity occurs. The noise level values need not be applied to areas having limited human use or where lowered noise levels would produce little benefit. Such areas would include but not be limited to junkyards, industrial areas, railroad yards, parking lots, and storage yards.

c. The interior design noise level in Category E applies to indoor activities for those situations where no exterior noise sensitive land use or activity is identified. The interior design noise level in Category E may also be considered as a basis for noise abatement measures in special situations when, in the judgment of FHWA, such consideration is in the best public interest. In the absence of noise insulating values for specific structures, interior noise level predictions may be estimated from the predicted outdoor noise level by using the following noise reduction factors:

Building Type	Window Condition	Noise Reduction Due to Exterior of the Structure	Corresponding Highest Exterior Noise Level Which Would Achieve an Interior Design Noise Level of 55 dBA
All	Open	10 dB	65 dBA
Light Frame	Ordinary Sash		
	Closed	20	75
	With Storm Windows	25	80
Masonry	Single Glazed	25	80
Masonry	Double Glazed	35	90

Noise reduction factors higher than those shown above may be used when field measurements of the structure in question indicate that a higher value is justified. In determining whether to use open or closed windows, the choice should be governed by the normal condition of the windows. That is, any building having year round air treatment should be treated as the closed window case. Buildings not having air conditioning in warm and hot climates and which have open windows a substantial amount of time should be treated as the open window case.

2. Exceptions

a. The design noise levels set out in these standards represent the highest desirable noise level conditions. State highway departments shall endeavor to meet the design noise levels in planning, locating, and designing highway improvements. However, there may be sections of highways where it would be impracticable to apply noise abatement measures. This could occur where abatement measures would not be feasible or effective due to physical conditions, where the costs of abatement measures are high in relation to the benefits achieved or where the measures required to abate the noise condition conflict with other important values, such as desirable esthetic quality, important ecological conditions, highway safety, or air quality.

b. A request for an exception to the design noise levels can be approved by the FHWA provided the highway agency has supported its request by a written summary report demonstrating that the following steps have been taken and outlining the results

(1) Identified noise sensitive land uses along the section of highway in question which are expected to experience future highway traffic noise levels in excess of the design levels.

(2) Thoroughly considered all feasible measures that might be taken to correct or improve the noise condition.

(3) Weighed the costs or effects of the noise abatement measures considered against the benefits which can be achieved as well as against other conflicting values such as economic reasonableness, esthetic impact, air quality, highway safety, or other similar values, and thereby established that reduction of noise levels to desirable design levels is not in the best overall public interest for that particular highway section.

These decisions must ultimately be based upon case-by-case judgment. However, every effort should be made to obtain detailed information on the costs, benefits and effects involved to assure that final decisions are based on a systematic, consistent and rigorous assessment of the overall public interest.

(4) Considered lesser measures that could result in a significant reduction of noise levels though not to the design levels, and included such partial measures in the plans and specifications to the extent that they meet the test of economic reasonableness, practicability, and impact on other values, in the same manner as outlined in paragraph 2b(3).

c. In reviewing request for exception, the FHWA will give consideration to the type of highway and the width of the right-of-way. New freeway projects and most projects for the major reconstruction or upgrading of freeways allow for the use of noise control measures. Noise control measures are progressively more difficult to apply on other highways, particularly on local roads and streets because of numerous points of access, at-grade intersections, limited ability to acquire additional right-of-way as buffer zones, and the impossibility of altering roadway grades, constructing noise barriers and taking advantage of the terrain and other natural features.

d. Except in the most unusual situations, exceptions will be approved when the predicted traffic noise level from the highway improvement does not exceed the existing ambient noise level (originating from other sources) for the activity or land use in question.

3. Noise Level Predictions

a. Noise levels to be used in applying these standards shall be obtained from a predictive method approved by the FHWA. The predictive method and the noise level predictions should account for variations in traffic characteristics (volume, speed, and truck traffic), topography (vegetation, barriers, height, and distance), and roadway characteristics (configuration, pavement type, and grades). In predicting the noise levels, the following traffic characteristics shall be used:

(1) Automotive volume - the future volume (adjusted for truck traffic) obtained from the lesser of the design hourly volume or the maximum volume which can be handled under traffic level of service C conditions. For automobiles, level of service C is considered to be the combination of speed and volume which creates the worst noise conditions. For those highway sections where the design hourly volume or the level of service C condition is not anticipated to occur on a regular basis during the design year, the average hourly volume for the highest 3 hours on an average day for the design year may be used.

(2) Speed - the operating speed (as defined in the Highway Capacity Manual) which corresponds with the design year traffic volume selected in paragraph 3a(1) and the truck traffic predicted from paragraph 3a(3). The operating speed must be consistent with the volume used.

(3) Truck volume - the design hourly truck volume shall be used for those cases where either the design hourly volume or level of service C was used for the automobile volume.

Where the average hourly volume for the highest 3 hours on an average day was used for automobile traffic, comparable truck volumes should be used.

b. There are instances where activities associated with a particular land use (such as churches, schools, and resort hotels or residences) do not coincide with design hourly volumes. This may be particularly true when the design hourly volumes are seasonally oriented or where the activity associated with the land use is somewhat infrequent. There are other instances where changes in land use can be reasonably expected to occur before design year volumes are realized. In such instances, State highway agencies may request approval to compute noise predictions using traffic characteristics different from those specified in paragraph 3a. Such requests should be made on a project-by-project basis and should be accompanied by a justification.

TABLE 1

DESIGN NOISE LEVEL/LAND USE RELATIONSHIPS

Land Use Category	Design Noise Level - L_{10}	Description of Land Use Category
A	60dBA (Exterior)	Tracts of lands in which serenity and quiet are of extraordinary significance and serve an important public need, and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose. Such areas could include amphitheaters, particular parks or portions of parks, or open spaces which are dedicated or recognized by appropriate local officials for activities requiring special qualities of serenity and quiet.
B	70 dBA (Exterior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, picnic areas, recreation areas, playgrounds, active sports areas, and parks.
C	75 dBA (Exterior)	Developed lands, properties or activities not included in categories A and B above.
D	--	For requirements on undeveloped lands see paragraphs 5a(5) and (6), this PPM.
E*	55 dBA (Interior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals and auditoriums.

* See paragraph 1c of this Appendix for method of application.